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Designing an intervention for creating awareness in motorists about vehicle emission consequences on human health

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Abstract Exhaust emissions from motorized vehicles are not only harmful to the environment but also on human health. At the same time, motorists are not necessarily aware of the adverse health effects resulting from their emissions. In this work, we use the health aspect as a primary motivation factor in the design of an intervention targeted at increasing this awareness. Based on research into the problem domain and the target group, we propose a design for a behavior-change intervention, consisting of an infrastructure of large public displays and a mobile application. In a design prototype, we incorporate two approaches, shaming and empowerment, designed to engage motorists with the intervention. An experimental evaluation of the prototype suggests that shaming can have a lot of potential in engaging motorists, while empowerment is also needed inside the application for helping the drivers reduce their emissions by means of more efficient traveling. Based on the findings, we discuss the role of personal data in the intervention and outline possibilities for realizing the design as part of the built environment.

1. Introduction

Many cities and densely populated areas suffer from poor air quality. Transportation networks, such as roads, are an integral part of the built environment and traffic on the roads contributes to air pollution. Exhaust gases from cars contribute not only to well-known greenhouse gas emissions such as carbon dioxide (CO_2) and nitrogen oxides (NO_x) but also to substances such as ultra-fine particles that are directly harmful to human health and can cause diseases such as cardiorespiratory morbidity and cancer (Weichenthal et al. 2014). In this paper, we propose a behavior-change intervention from the perspective of emission consequences on human health.

The testbed in this research is the city of The Hague in the Netherlands. The Netherlands is the most densely populated macro-country in mainland Europe and is continuously experiencing difficulties with air quality; for example, a 2017 court ruling obliges The Netherlands to reduce emissions to conform with EU standards, which have been exceeded in many of the larger cities of the country. The Hague contains several areas that belong to the top-20 list of air-polluted areas in the country (Milieudefensie 2017). A major contribution to these emissions is traffic. The Netherlands is infamous for its traffic congestion in urban areas and the main roads. While the road infrastructure itself is often blamed for the congestion, it can be argued that, ultimately, it is the behavior of the motorists that causes congestion and emissions. Traveling by car in the rush hour, suboptimal driving style, and using the car for short-distance journeys in the urban areas all accumulate to excessive emissions that could be reduced by alternative traveling behavior. Therefore, we are designing an intervention for one of the polluted areas in the city of The Hague to increase the awareness of car drivers on their

contribution to air pollution and its adverse health effects. Creating this awareness is the first step towards changing the behavior of the drivers. To maximize the impact of the intervention, we pay special attention to the use of personal data to inform the motorists of their contribution to the health of the surrounding community.

The main contributions of the paper are 1) investigating health effects of exhaust emissions as the driver of change in sustainable mobility; 2) comparing two different strategies to engaging people in the behavior change; and 3) discussing the role of personal data and the built environment in the proposed design. In the next section, we present related work on persuasion theories, sustainability interventions, and public visualizations. Subsequently, we outline the main research questions and challenges for designing an effective intervention. We proceed to explain our user-centered design process, followed by an account of initial design explorations and an evaluation of a design prototype. Finally, we discuss the value of the study and future work.

2. Related work

The problem of excessive exhaust emissions is in previous work often portrayed as a persuasion problem on mobility behavior. In this section, we outline general persuasion theories and previous work on designing behavior change in the transportation context. We also address using public visualizations to create awareness of civic issues.

2.1 Persuasion principles

Cialdini (1987) presented six principles of persuasion: reciprocation, authority, commitment/consistency, scarcity, liking, and social proof. *Reciprocation* means that a person has tendency to pay back favors from others; for example, getting a free item from a shop may invoke in the buyer the obligation to buy something more. *Authority* relates to the tendency of people to be more receptive to information and behavioral prompts from people they consider trustworthy experts. The *commitment/consistency* principle states that once people make a contribution to something, i.e., make a commitment, they are prone to follow that choice in their further actions. For example, spending money in a mobile game can make the player reluctant to stop playing that game. *Scarcity* refers to people desiring things that are rarely available and willing to stick to those things once they have been obtained. According to the *liking* principle, we are more receptive to requests that come from someone we know and like. Finally, the principle of *social proof* indicates that we have the tendency to be influenced in our actions by the behavior of others, i.e., conforming with social norms and showing it. These principles are present in many popular mobile applications and web services.

Fogg (2003, 2009) labels computational technologies deliberately targeted at changing the behavior of users or consumers of products and services as *persuasive technologies*. He has presented a model for understanding human behavior. The model considers three factors – triggers, ability, and motivation – that determine the likelihood that a person acts according to target behavior. If the person is willing and able to perform a certain action, an effective trigger can be used to nudge the person to behave accordingly. If, however, either the motivation or ability is lacking, the trigger remains ineffective. For example, if a person has plenty of money but does not see the reason to buy an eco-friendlier car, a trigger is not going to make the person buy the car. This suggests that persuasive technology should, when needed, affect the

motivation and/or ability of the person to perform according to the target behavior before a trigger can be applied.

2.2 Mobility behavior and motivation

Following Fogg (2003), understanding the existing motivations is important to design persuasive interventions. Related to mobility motivations and attitudes towards sustainability, Anable (2005) studied the travel behavior of motorists through a questionnaire based on attitudinal theory. She arrived at six behavioral segments: (1) *discontented drivers* (35% of the respondents), who would be willing to reduce their car use but find it difficult to do so; (2) *complacent car addicts* (26%), who would likely be able to adjust their lifestyle to reduce car use but lack the awareness of why it should be done; (3) *no-hopers* (19%), who lack any motivation to reduce their car use and are unlikely to be affected by social norms; (4) *aspiring environmentalists* (18%), who have a strong sense of environmental responsibility and are actively seeking alternatives for the car; (5) *car-less crusaders* (4%), who avoid the use of the car for the good of the nature; and (6) *reluctant riders* (3%), who are concerned by the negative aspects of driving a car but dislike alternative modes of transportation even more.

Choosing an alternative mode of transportation instead of the car can significantly improve the air quality in urban areas (Johansson et al. 2017). In a focus group study on efficient driving practices in New Zealand, it was discovered that people were aware of efficient driving styles and what they could do to act better for the environment to reduce carbon dioxide emissions, but did not act accordingly. They were mainly motivated by monetary incentives, i.e., savings in fuel costs. The study calls out for better-crafted persuasive messages that clearly link driving behavior with its consequences. Geng et al. (2017) have concluded that this kind of a gap between motivation and behavior should be bridged with tailored education and economic incentives.

2.3 Persuasive technology interventions for sustainable mobility

The current state of ubiquitous computing and sensing technologies has created opportunities for repurposing parts of the built environment to track the actions and behavior of people situated in the environment (Greengard 2015). Indeed, sustainability is an active topic in the field of ubiquitous computing (Zapico et al. 2009) and behavior change (Froehlich et al. 2010; Brynjarsdottir et al. 2012; Gabrielli et al. 2014). Many cities already track the behavior of inhabitants in various contexts, such as movement of vehicles in the transportation network and public engagement with the services of the city (Kitchin 2014). The data could also be used to inform persuasive interventions.

In the field of transportation, various persuasive technologies focusing on reducing carbon dioxide emissions have been proposed (Anagnostopoulou et al. 2016, Klecha and Gianni 2017), ranging from personalized journey planning applications (Schrammel et al. 2013) and automated tracking of mobility behaviour (Mun et al. 2009, Froehlich et al. 2009) to actionable challenges using transportation mode detection (Jylhä et al. 2013, Hemminki et al. 2013) and social, community-based approaches (Gabrielli et al. 2014). In the case of UbiGreen (Froehlich et al. 2009), the feedback is presented as a visualization that makes use of metaphors such as a melting iceberg to link the emission data to phenomena that people can relate to. It is noteworthy that virtually all of the previous work on changing the behaviour of motorists to reduce exhaust emissions justifies the need for persuasion based on reducing CO_2 emissions and relies on subjective motivational factors, such as monetary savings, gamification, or social comparison, as additional triggers or feedback visualizations (Anagnostopoulou et al. 2016,

Klecha and Gianni 2017). The effect of exhaust gases on the air quality and health has received less attention; in fact, to the authors' knowledge, the only examples in the field of sustainable mobility that justified the persuasive technology primarily based on air pollution and health are UKKO, a persuasive game by Dickinson et al. (2015) designed to encourage school children to walk to school instead of getting a ride on the car; and a study by Blom and Hänninen (2012), who concluded through co-design that personalization, positive focus, and active role of users would be important in the design of a persuasive air quality service. Based on this omission in previous work, we identify using air pollution and the related health effects as an underexplored domain in persuasive technologies targeting car drivers.

2.4 Public visualizations as agents for awareness and change

Above, we addressed mainly smartphone-based persuasive technologies for sustainable mobility, which rely on personal displays. In the domain of public visualizations, large public displays have been proposed for creating awareness of civic issues. DiSalvo et al. (2014) have discussed the role of human-computer interaction in expressing *matters of concern* such as civic issues through public visualizations. One of their design cases, Smog is Democratic (also Kim and DiSalvo 2010), related to presenting air pollution through a series of interpretive and expressive visualizations, which aimed at combining factual information and experiential or "lived" qualities of air pollution. DiSalvo et al. (2014) conclude that public, speculative, and reflective design can provide a means for human-computer interaction to express matters of concern. According to Schoffelen et al. (2015), the effectiveness of such designs depends on their readability and transparency. Through an analysis of three design cases, they conclude that making sense of a complex public issue can be facilitated by contextualizing the visualization by location and medium, providing access points for observers to participate, and, in case of interactive visualizations, by staging interactions instead of relying on free exploration. Related to contextualizing a large public display, Huang et al. (2008) recommend, for example, to take into account how much time viewers are expected to spend near the display, to minimize the time required to view and comprehend the most important content, to not rely on the screen capturing the viewers' attention but place the display in a location that has other distinctive features, and to use dynamic visualizations.

3. Research questions

Public visualizations may be effective for creating large-scale awareness of a civic issue such as air pollution. However, based on the persuasion theories and persuasive technology studies, principles of personalization, social proof, and actionable feedback are important for changing the behaviour of individuals. These principles rely on personal data of individuals, which brings forth the following challenges: 1) Motivating behavior change; 2) From personal data to shared data; 3) Avoiding the "surveillance city" (Shepard 2011) dilemma; and 4) Volunteering to share the data. In this section, we outline research questions related to these challenges.

3.1 Motivating behavior change

Our eventual aim is to increase awareness and stimulate behavior change. Awareness of consequences of current behavior will require extrapolation and aggregation of data: "if everyone would behave like this all the time, then…" It also requires presenting convincing possibilities to change and achieve significant improvements. This leads to the research question:

- How to convincingly show that alternative behavior in driving can significantly reduce negative consequences?

3.2 From personal data to shared data

A possible solution to displaying the feedback to the driver is a large roadside display. The benefit would be that also the surrounding community becomes aware of the air pollution phenomenon. In this case, a challenge is to design the feedback in a way that is informative to the driver and the community, but does not lead to stigmatizing the individual driver. This leads to the following research question:

- What data should be displayed, in public and in real time, to make both the driver and the community aware of the emissions and their consequences, while respecting the privacy of the driver?

An alternative to the public display would be to utilize a personal display such as the smartphone. A well-known challenge in this approach is that the drivers would have to "opt-in" to access the data, i.e., willingly use a mobile application on their personal device. This yields the question:

- How to motivate drivers to access the data related to the emissions of their vehicle?

3.3 Avoiding the "surveillance city" dilemma

While the air pollution problem is shared by all the inhabitants of the city, drivers might be reluctant to make use of the feedback if it comes from a system that they consider as policing. Thus, an important research question for user-centered design activities is:

- How to present the intervention in a way that is not perceived as policing by the drivers?

3.4 Volunteering to share the data

Closely related to the previous challenges is a traditional privacy conundrum. For the system to be effective, it would need access to data such as instantaneous speed of the car, which can be considered as personal data that drivers might not be interested in sharing with the system. The sensors could, of course, capture this data anyway, but without an "informed consent" of the driver there is a risk to introduce the perception of a surveillance city, which would likely have a negative impact on the effectiveness of the system. Thus, we arrive at the following question:

- How can we motivate drivers to share their data with the system?

4. Research into the stakeholders and the target group

The research questions and previous work suggest that motivational aspects and effectiveness of displayed data are key elements to explore. Therefore, we decided to focus the research on qualitatively examining the motivations and attitudes of the primary target group, i.e., the motorists. We used ethnographic research methods, more specifically a combination of in-situ observations and interviews, to uncover the members' point of view. In addition to the field research, we wanted to understand the complex interconnections of various stakeholders that play a role in the exhaust emission problem.

4.1 Stakeholder analysis

To map out the key stakeholders and their interests and influence related to the exhaust emissions, we performed a stakeholder analysis. The key stakeholders and their stakes are summarized in Table 1.

Table 1. Stakeholder analysis.

Stakeholder	**Interests**	**Has influence on…**
Inhabitants	Clean air Traffic safety Less traffic	Own neighborhood The municipality and the government
Motorists	Free mobility Alternative routes Fluent traffic	Air quality Traffic safety Driving behavior Public opinion Sold vehicles
Government	EU norms Paris climate accord Moral responsibility Civic participation Economical responsibility	European policies National policies Taxation Grants and subsidized funding Legislation Information
Municipality	Quality of life Business atmosphere Social infrastructure	Policies Taxation Legislation Subsidized funding Information
RIVM*	Public health Quality of the environment	National health norms Information bank on public health
Milieudefensie**	Environmental responsibility Societal awareness over environment Donations	The government / policy making Opinion makers
ANWB***	Education of motorists Representation of motorists	Motorists Government
Public transportation	Quality of service Attracting customers	Mobility Alternative means of transport
Innovators	Renewing the market Making money	New ideas to the market

* RIVM (Rijksinstituut voor Volksgezondheid en Milieu) is The Dutch National Institute for Public Health and the Environment.
** Milieudefensie is a Dutch environmental organization and action group.
*** ANWB (Algemene Nederlandse Wielrijdersbond, The Royal Dutch Touring Group) is a travelers' association, which is responsible for example for traffic signs and signage on roads.

The stakeholder analysis outlines the complexity of the field of exhaust emissions. In our research, the inhabitants are the central stakeholder. They desire a clean and safe environment to live in and can influence local policies through the municipality and the government. The

government, on the other hand, is concerned about air quality in general. As a key interest, the government aims at meeting the European norms for air quality and can use policies, legislation, and taxation of motorized vehicles to influence the air quality. The municipal authorities aim at making The Hague a good place to live in. Their interests include, for example, the health and safety of the inhabitants. Municipal policies are the primary means for meeting the interests. Agencies such as RIVM and Milieudefensie aim at educating the people about environmental and health issues and influence policy making of the legislative authorities. RIVM also maintains an information bank on public health.

4.2 Observations

We chose a particularly polluted area in The Hague, the Archipelbuurt, to observe the context. This is a relatively wealthy area, with many embassies and consulates as well as regular houses. We used a combination of non-participant observation and contextual inquiry. The non-participant observation was deployed to get a glimpse at the traffic, the vehicles, and the people living in the area. Contextual inquiry was used to discuss air pollution and traffic with people living or working in the area.

The observations focused on and around the main road in the Archipelbuurt. Many of the cars in the area were relatively large, with diesel and gasoline motors. There was a speed display on the road, and what seemed to be a relatively strict parking policy. These findings indicate that the municipality has been taking some measures towards keeping the traffic and the emissions in control. However, according to a worker we encountered in the area, the traffic problems still persist and especially during peak hours in the morning the street is full of cars. A local inhabitant explained to us that the municipality is indeed aware of air pollution, and therefore the roadside windows of the houses were equipped with ventilation grilles that filter air and noise.

4.3 Interviews with inhabitants

Through a set of interviews, we aimed at exploring the inhabitants' driving behavior, awareness of exhaust emissions and their consequences, and attitude towards environment and pollution. We also asked what kind of aspects they would consider important in a mobile application that would help them reduce exhaust emissions. We interviewed 6 people (4 males, 2 females, age range 34 – 55). All interviewees had a driver's license and a job. Two of the interviewees lived outside The Hague but worked in the city. All respondents were either married or in a long-term relationship. Three respondents had children.

On average, the respondents reported to drive daily 35.9 km (min 5 km, max 100 km). The main purpose of using the car was commuting to work (5 out of 6 respondents). One respondent used the bicycle for commuting, but the car for weekend trips with the family. The awareness of exhaust emissions varied between the respondents. Two respondents did not know what exhaust emissions were. Two respondents were very well aware of the emissions and their consequences. One respondent said that she didn't care about emissions and saw no reason to change anything in her behavior.

When asked about the type of car they are driving, one respondent first started listing various kinds of vehicles including, e.g., a diesel car and a motorcycle, but then abruptly stopped listing and stated to drive a hybrid car. Interestingly, when asked about a possible mobile application on air quality and driving behavior, the respondents didn't necessarily consider data privacy issues at all. One respondent did, however, state that it would be ok if the application gives

notifications but if they would be too frequent, he would uninstall the application and stop using it. Another one noted that he would trust the application if the service would be provided by the authorities (government / municipality), but not if the application would be commercial. This is well in line with the principle of authority (Cialdini 1987).

4.4 Interview with local mobility expert

In addition to the inhabitants, we interviewed a local mobility expert; the head of the traffic committee of the Archipelbuurt borough. He stated that he does not consider the high number of cars the core problem but rather the unnecessary and inefficient use of private cars. His proposed solutions include using the car more efficiently, distributing traffic on more routes and different times of day to mitigate congestion, and, in general, breaking the existing habits of the users of motorized vehicles.

4.5 Analysis of research results

We used inductive categorization to distill and analyze the research data from interviews, observations, and literature. We wrote the research findings on color-coded sticky notes, color depending on the source of information, and grouped similar items together. Six categories emerged: (1) Attitudes and motivation, (2) reasons to change driving behavior, (3) means for changing driving behavior, (4) transportation objectives, (5) awareness of emissions, and (6) conflicting interests. Aspects related to the design of a potential mobile application were grouped together with category 3.

This data analysis gave further insight into the complexity of the problem. On the one hand, the reasons to change driving behavior are clear: the negative health effects that can be attributed to traffic emissions are a real problem. However, only a subset of people is aware of the health effects. The "Attitudes and motivation" category reveals that people did not necessarily aim at environmentally friendly behavior, but showed signs of feeling guilty during the interview or even changed their responses when confronted with the problem. These findings can be useful in the design, because they not only suggest what information to present to increase awareness, but they also indicate that people can be emotionally responsive to the information.

The transportation objectives are mainly based on the expert interview and literature. They provide broader mobility aims that would reduce exhaust emissions; for example, reducing the use of private cars by 10%, using the car more efficiently, and improving traffic flows by distributing traffic in congested areas. This kind of objectives can serve two purposes in the design: provide justification to people seeking alternative means of traveling and serve as indicators for measuring the success of the intervention.

The interviewees were rather resourceful in coming up with suggestions for "means for changing driving behavior". Providing suggestions for alternative routes was a prominent theme and the respondents called out for clear visualizations indicating greener or faster routes and potential congestion spots or unexpected traffic situations. Alternative means of transportation were also suggested, as well as instructions for driving at a lower speed, which would consume less fuel and result in less exhaust gases. Combined with persuasion principles such as positive reinforcement, social proof, and personalization, this kind of suggestions could be considered as features for the designed intervention.

Related to alternative means of transportation, some people expressed negative attitudes towards public transportation, which was considered too slow, costly, or inconvenient. An interesting dichotomy was also found regarding bicycles: while there is mostly consensus of the cleanliness and positive health effects of riding a bicycle, some respondents thought that there are already too many bicycles riding in the urban areas and that riding a bicycle might result in getting exposed to the polluted air, whereas in a car the air filters get rid of some of the pollution. These findings suggest that not all the people can be motivated to change their transportation mode, but should instead be educated to use their motorized vehicle more efficiently.

4.6 Conclusion of research findings

Based on the research, we can conclude that the inhabitants of The Hague are a heterogenic group in terms of their mobility behavior, awareness of exhaust emissions, and motivation to work for a clean environment. The interview results are well in line with the travel behavior segments of Anable (2005): we can identify a "no hoper", a "complacent car addict", an "aspiring environmentalist", and a couple of "discontented drivers".

Due to the heterogeneity of the target group, we arrived at a conclusion that an effective design would likely need to contain multiple mechanisms that engage people, following the principle of personalization. Based on the interviews, some people are aware of the harmful consequences of their driving, but do not know how they could change their behavior (discontented drivers). On the other hand, some people are not aware of the adverse health effects of the exhaust emissions, and therefore do not see a reason to change (complacent car addicts). Grounding the design on this dichotomy calls out for two complementary strategies for engaging the people; we call the strategies *empowerment* and *shaming*. By empowerment, we mean providing actionable advice on more effective or less harmful transportation means to the people who already have awareness and motivation to change but are lacking the means to do so. Shaming, on the other hand, refers to confronting the people with the consequences of their behavior on the health of others. These two strategies, together with the synthesized results of the research, comprise the rationale for the proposed design for the intervention.

5. Design

Based on the research results and persuasion principles of Cialdini (1987) and Fogg (2003), we started forming design concepts tuned to making motorists aware of the health effects of their exhaust emissions. In this section, we first describe our of initial concepts. These concepts were used to get feedback from the target group in order to assess which elements they deemed essential and appropriate in such a design. The feedback was used to converge to a proposal for the design of the intervention, built around the principles of shaming and empowerment.

5.1 Initial concepts

We designed five different initial concepts. The concepts were designed to be complementary in order to see how the target group would respond to different approaches, reserving the possibility to later combine essential elements of each concept into a consolidated design. The five concepts are summarized as follows:

Aira A large digital board on the side of the road in the polluted area, displaying an ill child immersed in smoke with a message that relates the child's condition to air quality and exhaust

emissions. This concept implements the strategy of shaming. The board could also be used for positive reinforcement messages. Figure 1 depicts how the concept could look like in practice.

Airficient An application that lets the user plan beforehand a journey based on what kind of activities they are doing. For example, based on user input, the application would propose the most efficient route for combining commuting, grocery shopping, and picking up children from day care. The planning would be augmented with feedback that displays how much the user is able to improve their behavior based on the recommendations provided by the application. The feedback would relate to exhaust emissions (NO_3 and ultrafine particles). This concept follows the strategy of empowerment.

Nudgy An artificial intelligence component, such as a small robot on the dashboard, which acts as a traveling companion in the car. Nudgy would give real-time feedback on the driving style and information about problems ahead such as possible traffic jams or road construction work, suggesting alternative routes when necessary. Nudgy is primarily suited for the empowerment strategy, but the feedback could be tuned also towards shaming if the user fails to comply with the recommendations.

Run your airea A social application, integrated with a social networking service, meant for the residents of a neighborhood to work together towards a common goal of reducing exhaust emissions. The application would present air quality data to the users and show how they together contribute to the air quality in the area. The social features would enable members to take initiatives and share tips for reducing the emissions, for example through car-pooling or information about fluent routes around the area. This concept combines empowerment and shaming.

E-mission A game based on the idea of reducing exhaust emissions. The game could be set up as a competition between the residents of a neighborhood or a group of people who live further apart but want to compete with each other. In an alternative mode, groups of people could form teams that compete with other teams. This game would follow the principle of social proof and could also combine the strategies of shaming and empowerment.

Figure 1. Visual representation of the Aira concept as presented to the target group. The Dutch text on the board means “Grant your child clean air”.

5.2 Feedback from the target group

With the five concepts, we approached the target group to get their input. We obtained feedback from six motorists and the mobility expert. The motorists were not the same as in the earlier interviews. We explained each concept to them with a visual representation of the concept. We asked the participants to rank the concepts in their order of preference. This ranking was then used to discuss with the participant which elements in the concepts they considered useful or appealing and which ones they were less enthusiastic about.

The three concepts that received overall the most positive response were Nudgy, Airficient, and Aira. With Nudgy, the participants appreciated the idea of a helpful travel companion that would be always available for advice. They noted, however, that a robot might not be a practical form factor, because it could break or become a visual distraction. One participant suggested that maybe the functionality could be integrated in the on-board computer. The respondents considered Airficient as a practical tool. It became evident, however, that the purpose of using this kind of a tool depends on the individual. One participant was interested in seeing how many kilocalories they burned by taking the bicycle instead of the car, while two commented that they would be interested in seeing different kinds of feedback such as emissions and savings in money. Two participants perceived this functionality as another navigation application, of which there are already many in market. They suggested that this functionality could still be used to augment the design. Aira was the top choice for two participants. They considered it an asset that the board would be seen by every road user, who would thus be directly confronted with the problem while they are driving. One participant understood that the combination of a photograph and informative message would invoke emotional responses

in people, while another one suggested that the board could also be used to give tips for avoiding rush hours.

The social concept also got positive remarks. The main value to the respondents was that people could communicate with each other about their behavior, thus inducing social pressure. The game-like E-mission concept received the lowest score overall. It was considered far-fetched by one respondent, while another one stated that there are already enough games on the market. The mobility expert stated that all of the concepts seem valuable and could be used together to design an intervention. Using elements of all the concepts could result in a design that appeals to different kinds of people. In his opinion, the social network-based concept was the most promising one.

5.3 Proposed design

We decided to use elements from all the concepts except for the game in a consolidated design. The proposed design, OurAir, makes use of a combination of a roadside display and a mobile application. We concluded that a large roadside display would serve as an effective entry point. The board can be used for both shaming and empowerment and would be placed on a spot with congestion problems. For shaming, we use visuals of a sick child with the message such as "Grant your child fresh air" while for empowerment, the visuals can be a traffic jam with the text "Do you want to get there faster and cleaner?" The board can also display a prompt to download the application.

It is not guaranteed that just seeing the board is enough, so we want to remind people of the message they potentially saw while driving. Based on the fact that there is already smartphone functionality such as Google Nearby that allows for location-aware third-party advertisements, we can use integration with such a platform, combined with proximity sensing to the board, to detect drivers who pass the display. Once the driver passes the display or stops the car, the third-party platform can be used to send a pop-up notification to the driver. The notification would contain a message "Did you see this board?" with an image of the board, and an option to answer either "yes" or "no". The next step depends on whether the board contained a shaming or empowerment message. If it was shaming, answering "yes" leads to a follow-up question whether the person is willing to help the sick child or not. If the person answers "yes", they get a prompt to download and install the OurAir mobile application. If, however, they answer "no", they are shown a short video about exhaust emissions and their health effects. After the video they can again choose to either download OurAir, or reject the prompt for a second time. If they decline, they still see some facts and figures on pollution-related deaths and get one more chance at downloading. If the message on the board was about empowerment, the notification asks the same question as on the board and then prompts to the download page of the application. This can be accepted or declined. Answering "no" would lead to the same video as in the shaming approach. After downloading and installing the application, the user is requested to enter the data of their car into the application. The essential data consists of the make and model of the car, its average fuel consumption, and the type of fuel. Alternatively, the user can input their license plate number, which can be used to retrieve the fuel-related information from a database.

The key features of the application are (1) visual feedback on emissions and other metrics of the traveling behavior, (2) an activity planner that helps with traveling more efficiently, (3) display of personal statistics, and (4) the possibility to share own metrics to one's social network. Figure 2 (left) depicts a visual mockup for the home screen of the application upon

first use. The central element on the screen is an image of a child. The image changes depending on the exhaust emissions of the user of the application, depicting a healthy and happy child in one extreme or a seriously ill child in the other extreme. This way, the image can either provide positive reinforcement or remind the user that they should consider changing their traveling behavior not to harm others. Below the image, the application visualizes three scores: car score, distance score, and driving style score. The car score is determined by the car data the user entered. It is based on the average emissions of the particular car and the only way to update this score is by obtaining a different vehicle. The distance score is determined as a ratio between kilometers driven by car vs. kilometers travelled using other means. A low score indicates excessive car use. The driving style score is determined by monitoring the driving behavior. The score is reduced by too high speeds, irregular acceleration / deceleration, idling, etc. The driving style score can be estimated by tracking the driving with the sensors of the phone. In the bottom of the screen, an overall score is presented. When the score is low, the visualization depicts toxic gases and a gas mask; when the score is good (Figure 2 right), the visuals depict clean air. Figure 2 also depicts two flavors of the visualization: drawn and realistic. At this stage, we wanted to explore both options.

The activity planner helps the user to drive the car more efficiently. The user can enter a set of activities and the application provides a recommended route to meet all these activities. An existing navigation platform such as Google Maps can be integrated through its API to calculate the routes. Once the user has entered the activities, the application sends a routing request to the navigation application, which is thus launched and takes care of the navigation. After this, OurAir runs in the background to track the location and speed of the vehicle, in order to estimate the emissions as well as driving behavior. These metrics are stored during the journey and will be used to update the information on the home screen as well as the longer-term statistics.

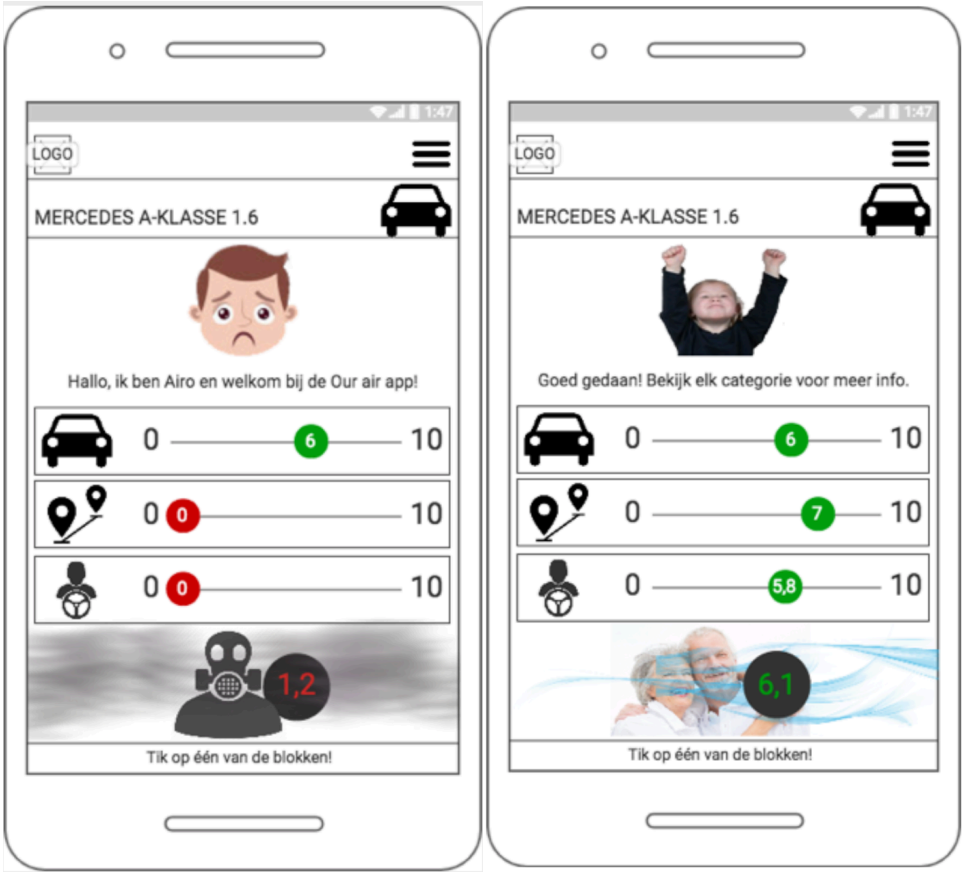

Figure 2. Visual mockup of the home screen of the OurAir application on first run of the application (left) and after successfully reducing emissions (right).

The home screen responds to traveling behavior. Figure 2 (right) depicts the home screen of a user, who has been using her car efficiently, according to the recommendations of the activity planner. The child is happy and the emission visualizations are green. The user can also check a separate statistics page for visualizations on how the metrics have evolved over time or get tips for how to increase the score. The user can opt to share their metrics to their social network and view the scores of others. The purpose of this feature is to provide the user with means for social proof and make more people aware of the application and the exhaust emissions. This feature could later be expanded also to create competition between individual users.

6. Evaluation of the design

We set up a small-scale experiment to explore the potential effectiveness of the design. In the evaluation, we chose to focus on how people would experience being confronted with such an intervention, comparing the empowerment and shaming strategies, and how willing people would be to share their personal data with the system. These two aspects were deemed to be the most important ones to study first, because for an application-based system the key challenge is to motivate people to download the application and engage in using it.

6.1 Method and procedure

The methodology in the experiment consisted of scenarios, a clickable version of the design prototype, and the think-aloud protocol. We made a clickable version of the prototype and

prepared three scenarios that involved operating the prototype. In the first scenario, the driver (participant) is driving home and an empowerment message is presented on the roadside display ("Do you want to drive cleaner and arrive at work on time?"). In the second scenario, the display presents a shaming message (Figure 1). In both scenarios, the driver gets a pop-up notification after parking the car, with a question about whether they saw the message on the board. The application then responds to the input of the participant as explained in Section 5.3. The third scenario relates to the activity planner functionality. The task is to plan a trip consisting of activities such as taking a child to school, visiting the bank, and grocery shopping. After the trip, the participant sees updated scores on the home screen and also the opportunity to share the score to others.

In the experiment, the prototype was presented on a laptop computer, and the experiment conductor was sitting near the participant giving instructions and taking notes. In all scenarios, the conductor first read an introduction and explained the task. In the first two scenarios, the screens depicting the roadside display and arrival at home did not require input from the participant, but after them the participant was shown the clickable prototype with the pop-up notification, which they were allowed to operate independently. In the third scenario, after the introduction, the participant was told to operate the application to plan the route for the given activities. After all the scenarios, the participant was handed a questionnaire and interviewed. The questionnaire focused on the participant's reaction to receiving the location-aware pop-up notification, sharing personal data in the application, the effectiveness of shaming vs. empowerment and realistic vs. drawn imagery, and their attitude towards sustainable mobility following Anable (2005). The interview was used to ask follow-up questions based on the questionnaire answers. The session was audio recorded.

6.2 Results

Five participants (all male, average age 30, here referred to as P1 to P5) were recruited for the experiment. Based on the post-test interview, P1 was a clear no-hoper, P3 had very eco-friendly values, and the three others were from between these two extremes. Three of the participants had children.

All participants considered the shaming approach to be more effective than empowerment and preferred realistic imagery. The participants with children commented that shaming was emotionally connecting with them, especially through the message "Give your child clean air". Four out of five participants opted to download the application. P1, the no-hoper was not convinced; he stated that the imagery was not strong enough to convince him and that while he appreciated the initiative, he was "cynical" about whether people would use the application. However, he said that if the application would become nationally known and promoted with an effective campaign, he would use it. P2 was convinced only after the screen with facts and figures about pollution effects was shown; he also called out for stronger imagery. As an additional motivation factor to use the application, four participants said that they would like to be shown how much money they save in fuel costs by following the advice of the application.

Regarding privacy and personal data, the reactions were mixed. The location-aware pop-up notification was not an issue for P1, P4, and P5, but P2 said that he would feel like being watched and he would prefer another kind of means for getting the first contact with OurAir. P3 said that as long as it is not for commercial purposes, he has no objections, even though he would feel "shocked" for getting the pop-up. He said that if there would be a clear connection to a trusted authority such as the government or the municipality, he would feel more secure.

Regarding sharing of data, the participants mentioned banking details, home address, and in one case the license plate number as data they would not be willing to share. None of the participants expressed concerns about sharing their location or driving statistics to the application; however, for P4 it would be important that his data would not be accessible by third parties.

7. Discussion

While the design of the intervention is still a work in progress, we can already provide some interesting conclusions. In general, we can conclude that using the effects of exhaust gases on human health seems like a very promising direction for persuasive technologies in the field of sustainable mobility. The aim is to make the use of a part of the built environment – the road infrastructure – smoother and healthier for the surrounding communities. Regarding our first research question, "How to convincingly show that alternative behavior in driving can significantly reduce negative consequences", the shaming approach seems to provide the answer. The imagery of sick children and polluted air affected the test subjects emotionally, providing a potential mechanism for increasing the motivation of people to change their behavior, which is required according to Fogg (2009). For alternative behavior, the empowerment component of the application, i.e. the activity planner, is important to also provide people the ability to change.

Related to motivating drivers to access their data, i.e. participate in the intervention and download the application, the location-aware pop-up notification seems to have potential. Only one participant in the experiment considered it a barrier and based on the results it seems that people are already quite used to getting notifications and advertisements on their devices. It is interesting that there is also evidence both from the interviews and the experiment that the notification, and the application itself, would be perceived as trustworthy if they were visibly endorsed by the authorities. In this case, the key to avoiding the perception of being watched in a "surveillance city" (Shepard 2011) seems to be to explicitly link the design to the municipality or the government.

The participants of the experiment had limited reservations about sharing their data with the application. We already live in an era, where people are accustomed to sharing their data to a multitude of applications and services. It is, however, still important for people to understand who will have access to their data and why. Transparency is crucial to ensure that people would install an application such as OurAir. Parts of the design rely on third-party services from multi-national organizations, which has implications on data protection and privacy. There might even be legislative restrictions to take into account in involving such partners in the intervention, depending on where and how they store the data. This aspect needs to be further explored in dialogue with local authorities.

Through the initial exploration presented in this paper, we did not yet fully address the research question about what data should be publicly displayed to communities and how. This is a key aspect of the future work we envision, as it can provide a means for local communities to create shared awareness of the air quality issue and, potentially, support joint initiatives for behavior change. While the designed application does contain a social sharing component, this is restricted to the social circles of the user and personal displays of the smartphone. An exciting prospect would be to use distributed and networked public displays as part of the design.

According to Memarovic (2016), networked public displays can provide a medium to facilitate civic engagement, support exchange and interaction between community members, and enable leaving a mark in the setting, all of which can work positively towards creating shared awareness. In the contextualization of the public displays, we need to take into account the surrounding context as well as suggested by Huang et al. (2008) and Schoffelen et al. (2015): especially for the motorists, the time they can look at the display is often very short, so the messages need to stay compact and the displays need to be localized so that the message catches attention. We can envision using existing infrastructure like bus stops to contextualize the displays and bridge the gap between physical and digital.

In the proposed design, the roadside display is only used as a passive display aiming at engaging drivers with the design. The display could also be used for personalized positive reinforcement. If a user is detected to be driving towards a display, it could be used to display a personalized message, for example, thanking the user that she/he has not had a negative impact on the health of others. This could be achieved by tracking the location of the driver by means of the application and projecting the expected moment when the driver reaches the vicinity of the display. It should be noted that the roadside display cannot be realized without the support of the municipality and/or ANWB.

A limitation in the study is the small sample size. However, the findings already provided support for key elements in the design and also provided insight into how to refine the design for the next iteration. Based on the findings, we will focus on revising the messages and imagery in the two approaches before experimenting with a functional prototype. Another limitation is that we only showed the participants of the experiment one message for shaming and one for empowerment, so we still need to experiment with alternative messages while working on the next iteration of the design.

8. Conclusion

In this paper, we explored the design of an intervention targeted at creating awareness in motorists of the consequences of their exhaust emissions on human health. While there are many persuasive technologies built with the rationale of motivating people to reduce their carbon dioxide emissions, we chose to focus on other types of emissions and their impact on human health as the main motivational factor in the intervention. Through a user-centered research and design process, we have arrived at a proposal for the design, making use of large side-of-the-road digital displays and a mobile application, which together are designed to make people more aware of the adverse health effects of exhaust emissions and to help people find ways to decrease the harmful emissions. Through two strategies, shaming and empowerment, we have designed two flavors for the intervention to potentially reach a broader group of road users, whose motivations to act in an environmentally friendly way differ. Initial explorations indicate that shaming seems to be the more effective approach and that it is important to connect the design with authorities for the perception of trustworthiness.

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